(11) (A) No. 1 225 889

(45) ISSUED 870825

(52) CLASS 128-8

4

(51) INT. CL. A61H 31/00, A62B 7/00

(19) (CA) **CANADIAN PATENT** (12)

(54) Method and Apparatus for Applying High Frequency
Extrathoracic Induced Breathing

(72) Chang, Hsin-Kang;
Zidulka, Arnold,
Canada

(21) APPLICATION No.    450,810

(22) FILED    840329

(30) PRIORITY DATE    U.S.A. (480,798) 830331

No. OF CLAIMS    2

Canada

EXHIBIT

6

H450810

Abstract of the Disclosure

A method and apparatus for providing cyclical extrathoracic compression and expansion to induce breathing to a living body is provided, whereby a flexible band may be adjusted around the thorax of the body to be treated, with expandable bladders provided within the band and a reciprocating air pump expands and retracts the bladders such as to provide compression and expansion to the rib cage of the body where the expansion and retraction is a

10    cycle between 1 and 20 Hz.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1.     An apparatus for providing extrathoracic induced breathing in a body comprising a flexible band adapted to be adjustably secured about the thorax of the body to be treated, and at least a pair of resilient expandable bladders provided on the interior of the band and adapted to be expanded against the rib cage of the body, conduit means communicating the bladders to a fluid source, reciprocating pump means associated with the fluid source for alternatively supplying a fluid under pressure through the conduit means to the expandable bladders and withdrawing the fluid, the pressures ranging between -10 cm. of water and 120 cm. of water within the bladders, the reciprocating pump means adapted to provide a sinusoidal reciprocating cycle frequency of between 1 and 20 Hz and having an amplitude such as to provide a tidal volume at the mouth of the body of 0.3 ml/kg and 3 ml/kg which decreases as frequency increases.

2.     An apparatus as defined in claim 1, wherein the reciprocating cycle is applied at a frequency of between 2 and 11 Hz.

16

The present invention relates to a method and
apparatus for high frequency respiration, and more particular-
ly for improved ventilation and/or airway clearance of a
patient by extrathoracic compression and expansion.

There have been a number of papers describing
induced respiratory ventilation at high frequencies, i.e.,
23 to 40 Hz, through an endotracheal tube, as described, for
instance, in D. J. Bohn et al in an article entitled
"Ventilation by High-Frequency Oscillation", J Appl Physiol:
Respirat Environ Exercise Physiol 1980:48:710-716, and in
W. J. Butler et al in an article entitled "Ventilation by
High-Frequency Oscillation in Humans", Anesth Analg 1980:
59:577-584.

The methods described in these articles as well as
other experiments with high frequency ventilation techniques,
include supplying a continuous flow of fresh gas to the
endotracheal tube by way of the mouth with superimposed
oscillations produced by a piston pump. The systems include
the use of frequencies of oscillation ranging up to 30 Hz.
It was thought, however, that the pulmonary gas exchange
was caused as a result of increased diffusion since in most
cases the methods resulted in small oscillatory tidal
volumes. It has been found, however, that any process
which involves an endotracheal tube passing in the airway
for the purpose of inducing high frequency ventilation may
cause some discomfiture and certainly temporary loss of
speech. The use of a mouthpiece for such purposes can
cause gagging.

Extrathoracic respirators, particularly cuirass
respirators, have been developed to assist in the normal
breathing patterns of a patient having various respiratory

- 1 -

**1225889**

diseases, such as poliomyelitis. A history of these devices
is provided in an article by C. H. M. Woollam entitled
"The Development of Apparatus for Intermittent Negative
Pressure Respiration", (2) 1919-1976, published in
"Anaesthesia", 1976, Volume 31, pages 666-685. These
devices have been developed in order to provide normal
respiratory assistance at frequencies below 20 cycles per
minute or 0.33 Hz.

     An apparatus has been described in relation to

10    clearing airway obstructions due to retained secretions by
utilizing an external thoracic vibrocompressor. This vibro-
compressor, which is described in an article entitled "Chronic
Bronchial Asthma and Emphysema" written by Gustav J. Beck,
M.D. and published in "Geriatrics", June 1966, comprises
using a cuirass in the form of a canvas belt supporting a
vinyl bladder and adapted to cover the lower thorax and
upper abdomen. An airflow is provided during expiration
only, which emanates from a compressor. This airflow is
passed over a vibrator operating at 1800 cycles per minute

20    or 30 Hz, thus transmitting a vibration to the belt or
cuirass. An actuating means is provided to initiate the
compressor on the patient's own expiration.

     It is an aim of the present invention to provide
a method and apparatus for providing ventilation by inducing
a high frequency vibration or oscillation to the air column
in a patient's airway in order to induce artificial breath-
ing and, therefore, gas exchange of air, oxygen, anesthesia
gases, aerosols, etc. It is also an aim of the present
invention to provide improved clearance of the airway in a

30    patient, due to lodged secretions within the airway.

     A method in accordance with the present invention

**1225889**

comprises the steps of applying extrathoracic compression and expansion at a frequency of between 1 and 20 Hz and a maximum peak pressure of 120 cm. of water to thereby provide a tidal volume at the mouth of between 0.3 ml/kg to 3 ml/kg, the total volume being smaller at higher frequencies.

An apparatus in accordance with the present invention comprises an apparatus for providing induced breathing to a living body comprising expansion and compression means for applying a cyclical extrathoracic compression and expansion to said living body, operating means communicating with a source of power for operating said expansion and compression means at a cyclical frequency of between 1 Hz and 20 Hz at a maximum pressure to the thorax of 120 cm. of water to thereby provide a tidal volume at the mouth of between 0.3 ml/kg to 3 ml/kg with the tidal volume decreasing as the frequency increases.

An apparatus in accordance with a more specific embodiment of the present invention comprises a flexible band adapted to be adjustably secured about the thorax of the body to be treated and at least a pair of resilient expandable bladders provided on the interior of the band and adapted to be expanded at least against the rib cage of the body. Conduit means communicate the bladders to a fluid source. Reciprocating pump means are associated with the fluid source for alternatively supplying a fluid under pressure through the conduit means to the expandable bladders and withdrawing the fluid. The pressures in the bladders range between -10 cm. of water and 120 cm. of water. The reciprocating pump means are adapted to provide reciprocating cycle frequency of between 1 and 20 Hz and have an amplitude such as to provide a tidal volume at the

- 3 -

mouth of the body of 0.3 ml/kg to 3 ml/kg inversely propor-

tional to the frequency.

During tests conducted on paralyzed dogs at fre-

quencies of 3, 5, 8 and 11 Hz, peak pressures applied at the

bladders ranged from 30 to 230 $cmH_2O$. This produced swings

of esophageal pressure as high as 18 $cmH_2O$ and peak oscilla-

tory airflow ranging from 0.7 to 1.6 L/sec. Oscillatory

tidal volume declined with increasing frequency and ranged

from a mean of 61 to 45 ml. After 30 min. of application

10 of this extrathoracic induced breathing, arterial blood gases

revealed a mean $PaCO_2$ of 29.3 mmHg at 5 Hz, 35 mmHg at 3 Hz,

36 mmHg at 8 Hz, and 51 mmHg at 11 Hz. Mean $PaO_2$ improved

from ventilator control values at 3 Hz, remained unchanged

at 5 and 8 Hz, and declined at 11 Hz.

It has been discovered that such high frequency

ventilation in unintubated human beings provides satisfactory

ventilation and could improve gas exchange.

Finally, by providing this high frequency ventila-

tion by chest wall compression and expansion, trauma is

20 avoided in the airway as well as improving the patient's

comfort and avoidance of any tubes within the airway.

It has also been found that by providing extra-

thoracic compression and expansion in the higher ranges of

the high frequency range, i.e., from 8 to 20 Hz, improved

mucous clearance has been achieved in patients suffering from

lung disease characterized by mucous hypersecretion.

In healthy subjects, the quantity of tracheo-

bronchial mucus is small, and ciliary mechanisms are adequate

to maintain clearance. In patients with lung disease charac-

30 terized by mucous hypersecretion, cough becomes an additional

clearance mechanism. If the mucous overload becomes too great

- 4 -

for these two mechanisms, then the result is an accumulation of secretions.

The use of physiotherapy or mechanical methods of augmenting clearance has been studied. The available litera- ture shows that chest physiotherapy, such as percussion, postural drainage and encouragement to cough, has been shown to improve clearance of radio-aerosol deposited in the tracheobronchial tree in patients with chronic obstructive bronchitis. In another study with similar patients, it was demonstrated that postural drainage, vibration at 12-16 Hz, percussion at 5 Hz and shaking at 2 Hz for 20 minutes plus encouragement to cough, resulted in a significant increase of secretions from the central, intermediate and peripheral lung regions compared to a control run. On the other hand, vibration alone ($41 \pm 5$ Hz; 2 mm amplitude) by means of an electrically driven pad applied to patients with chronic bronchitis for 1 hour, was shown to have no effect (D. Pavia et al, "A Preliminary Study of the Effect of a Vibrating Pad on Bronchial Clearance", Amer Rev Resp Dis 1976; 113:92-6).

By using the method of the present invention, it has been observed that with chest wall high frequency com- pression, the peak expiratory flow rate was greater than the peak inspiratory flow rate. This has been found useful in helping to clear mucus out of the tracheobronchial tree, especially when higher peak expiratory linear velocities at the air-mucous interface occurs during oscillation. Further- more, it has been shown that when sputum is subjected to high frequency oscillation in the range of 3 to 17 Hz, its viscosity is reduced. This tends to facilitate the removal of airway mucus, either by increased airflow interaction or by enhancement of ciliary clearance.

Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, showing by way of illustration, a preferred embodiment thereof, and in which:

Figure 1 is a schematic view showing a patient in a supine position to which an extra-thoracic band is mounted;

Figure 2 is a perspective view, partly broken away, of an embodiment of the extra-thoracic band;

Figure 3 is a vertical cross-section taken through line 3-3 of Figure 2;

Figures 4A to 4D are graphs illustrating various tests at different frequencies within the range; and

Figure 5 is a graph plotting a carbon spot test using the method in accordance with the present invention compared with conventional methods.

Referring now to the drawings, there is shown a band or cuff 10 made of a strip of canvas roughly 9 cm. wide and approximately 120 cm. long. The strip of canvas 12 is provided on the internal side thereof at the end 14 with a large strip of "Velcro"* 16. At the other end 18 of the strip 12 is a cooperating strip of "Velcro" 20 on the outside of the canvas strip. Centrally of the cuff 10 are a pair of double wall chambers 22 and 24 in which are provided rubber or the like bladders 26 and 28. Each bladder in the present embodiment is 12.5 cm. by 27 cm. Communicating with each bladder is a tube 30 having an internal diameter of 1.27 cm. connected to a molded Y connector 32 which in turn

* "Velcro" is a registered trade mark of Velcro S.A.

communicates with a conduit in the form of a flexible tube
34 to a reciprocating pump 36. The reciprocating pump is of
the conventional type. In the present embodiment, the pump
is driven by a variable speed DC motor which has a frequency
control. The pump must be large enough to provide a recipro-
cating cycle of expansion of the bladders 26 and 24 and
contraction thereof in frequencies of between 1 and 20 Hz
with peak pressures of 120 cm. of water.

Clinical tests have been made on dogs, and these

10      will now be described.

Six dogs weighing between 23 and 34 kilograms were
anesthetized and were placed supine, and a cuff 10 was
placed around the thorax of each dog with each bladder 24
and 26 positioned on respective sides of their rib cage and
with the caudad border of the cuff 10 at the level of the
xiphisternum. The tubing 34 was connected to a piston pump.
The piston pump consisted of a commercial air compressor
pump having two pistons in parallel. The valves of the pump
were rearranged so that the piston simply drove air in and

20      out. The pump was driven by a 3 horsepower variable speed
DC motor which had a frequency control (maximum frequency of
17 Hz). The DC motor had a small pulley connected by a belt
to a larger pulley which drove the piston. The larger
pulley also acted as a fan to cool the piston pump.

The cuff 10 was partially inflated by a bias
pressure. The bladders 24 and 26 each were provided with
small leak outlets, and air was pumped into the bladders at
15 to 20 liters per minute providing a pressure of 3 cm. of
$H_2O$. In addition to this bias pressure, the pressure was

30      oscillated by the pump. The variable leak was regulated so
that on withdrawal stroke of the piston, a slightly negative

cuff pressure (Pcuff) developed. This served to partially deflate the cuff 10 and allow the compressed thorax to expand normally, thereby inducing inspiratory airflow. Tidal volume at the mouth, whether spontaneous (Vts) or oscillatory (Vto) was assessed by integrating flow measured by a screen pneumotachometer (Hans Rudolf No. 4700) with a Validyne pressure transducer ($\pm$ 2 $cmH_2O$) attached to a 10 mm internal diameter endotracheal tube. The same attachments were used for the calibration of the oscillatory tidal volume (Vto) at

10    oscillatory frequencies ranging from 0.6 to 16 Hz. The data was recorded on a Hewlett Packard recorder model 7758A. During calibration, the other end of the pneumotachometer was connected through a tubing, 7 cm. by 2.54 cm., into a rubber stopper of a 4 liter airtight glass bottle. To measure pressure changes in the bottle, a 10 cm. long catheter having a diameter of 0.94 cm. was inserted through the rubber stopper with its other end connected to the Validyne pressure transducer ($\pm$ 50 $cmH_2O$) which had a known flat amplitude response to 40 Hz. The size of the bottle

20    and the connecting tube were selected so that minimal resonance would occur over the entire range of frequencies used.

For oscillating calibration, the ratio of integrated tidal volume to the reference tidal volume (yielded by the peak pressure variation in the glass bottle) at each frequency was used as a correction factor. This was found to be 1.00 at 0.6 Hz, 1.38 at each of 3 and 5 Hz, 1.05 at 8 Hz, 0.80 at 11 Hz, and 0.70 at 16 Hz.

For flow calibration, since the piston pump generated a nearly perfect sinusoidal flow, tidal volume

30    and maximum flow are related by

$$\dot{V} max = \pi f . Vt.$$

- 8 -

Thus, a correction factor for peak flow measurements at a given frequency may be obtained by taking the ratio

$$\frac{\dot{V} \text{ max measured at that frequency}}{\dot{V} \text{ max reference}} .$$

Esophageal pressure (Pes) used as a reflection of pleural pressure was calibrated by oscillating the pressure in a sealed bottle by $\pm$ 10 $cmH_2O$ with the piston pump at different frequencies. A 5 cm. balloon filled with 0.5 cc. air with 100 cm. of PE 200 tubing was placed in the bottle and led out to 267 B Hewlett Packard pressure transducer.

10    The pressure swings were compared with those of another reference 267 B pressure transducer which had short wide bore tubing leading directly into the bottle. The frequency response was flat to 7 Hz. At 11 Hz $\Delta Pes/\Delta P$ reference was 0.9 and Pes lagged by 24 degrees. While it is recognized that at high frequency there would be a damping effect by the mediastinum and esophagus, nevertheless it was felt that Pes would provide at least an underestimation of the pressures transmitted by the cuff into the thorax. In addition, in the supine position the change in esophageal pres-

20    sure may not provide an accurate measurement of mean pleural pressure change depending on the position of the balloon in the esophagus.

In six paralyzed dogs, ventilatory support was affected by the following. Ventilation at room temperature was supported for 30 minutes by a Harvard volume ventilator delivering tidal volumes of 10 ml/Kgm at 12/min. At the end of each of these periods, control arterial blood gases were measured (Instrumentation Laboratories - 813). The Harvard ventilator was then disconnected and alternated with the

30    cuff 10 for 30 minutes each at frequencies of 5, 8, 3 and 11

Hz. The cuff pressure (Pcuff) was measured, and the variable
leak was adjusted so that on the withdrawal stroke of the
piston, a slightly negative cuff pressure (Pcuff) occurred.
In order to minimize dead space, there were no attachments
on the endotracheal tube. Arterial blood gases were measured
after 20 and 30 minutes at each frequency. Thereafter, the
pneumotachometer was connected to the end of the endotracheal
tube and flow and volume were measured. While measuring
oscillatory tidal volume (Vto), the cuff oscillations were

10      suddenly discontinued, allowing a measure of that change in
volume to paralyzed functional residual capacity (FRC). This
change in FRC ($\Delta$FRC) provided a measurement of how far below
FRC the extrathoracic system was being applied. In two
dogs, cardiac output was measured by the thermo-dilution
technique using a Swan Ganz catheter. The cardiac output
during conventional mechanical ventilation was compared with
that produced with the cuff 10 at different frequencies. In
four dogs, quasistatic deflationary pressure volume measure-
ments of the lung and chest wall were made by electrically

20      integrating flow starting at a transpulmonary pressure ($P_{TP}$)
of 25 cmH$_2$O (TLC) after delivering at least 3 large infla-
tions prior to each measurement.

        Two dogs were initially kept anesthetized and not
paralyzed. While the dogs continued to breathe spontaneously,
induced respiration with the cuff 10 was applied at 5 and 11
Hz and 30 minutes each with each application preceded by 30
minutes of spontaneous ventilation without the cuff 10.
Arterial blood gases were measured at the end of each 30
minute period. In one dog with the cuff 10 at 5 Hz, arterial

30      blood gases were obtained every 10 minutes. Thereafter, the
pneumotachometer was attached, and Vto, Vts and the

frequency of spontaneous ventilation (fs) were obtained.
Spontaneous minute ventilation ($\dot{V}_{ES}$) was calculated as the
product of Vts and fs.

In Figures 4A to 4D, the mean results of Pcuff,
Pes, peak flow and Vto are given at 3, 5, 8 and 11 Hz in the
paralyzed dogs. On the forward stroke of the piston, the
mean peak Pcuff ranged from 80.4 $cmH_2O$ (gauge) at 5 Hz to
102.8 $cmH_2O$ at 11 Hz. On the back stroke of the piston,
the variable leak was adjusted so that mean peak Pcuff ranged
from -7.9 $cmH_2O$ at 3 Hz to -28.3 $cmH_2O$ at 11 Hz. This nega-
tive Pcuff allowed the chest wall of the dogs to recoil back
towards their paralyzed FRC with minimal impedance. As an
estimation of the pressures transmitted into the thorax, the
mean peak expiratory Pes ranged from 7.8 $cmH_2O$ at 3 Hz to
10.6 $cmH_2O$ at 11 Hz. The mean peak inspiratory Pes ranged
from -2.4 $cmH_2O$ at 3 Hz to -6.9 $cmH_2O$ at 8 Hz. The mean
peak swings in Pes ($\Delta$Pes) ranged from 10.2 to 17.3 $cmH_2O$ at
3 and 8 Hz respectively.

The peak flows produced at the mouth were signifi-
cantly greater on expiration than inspiration ($p < .005$) at 5
and 8 Hz. They were also greater on average at 3 and 11 Hz
but this did not attain statistical significance. The mean
expiratory peak flow ranged from .70 to 1.61 L/sec. The
mean Vto produced at the mouth was maximal at 3 Hz, that is,
61.0 ml, and decreased progressively with frequency: 53.3 ml
at 5 Hz, 47.9 ml at 8 Hz, and 45.1 ml at 11 Hz.

The mean $PaO_2$ achieved 20 and 30 min. post onset
of the cuff 10 was slightly higher than the control venti-
lator $PaO_2$ at 3 Hz. At 5 and 8 Hz the $PaO_2$ changed little
from control, whereas at 11 Hz the $PaO_2$ declined progressively.
The mean $PaCO_2$ at 3 Hz declined at 20 and 30 min. from a mean

control value of 41 to a mean of 34 and 35 mmHg respectively,

and at 5 Hz from 35 to 30 and 29 mmHg respectively. At 8 Hz

there was a minimal change from 39 to 36 and 36 mmHg respec-

tively, whereas at 11 Hz there was a progressive increase

in $PaCO_2$ from 35 to 47 and 51 mmHg respectively.

In the two paralyzed dogs where cardiac output was

measured, there was no change between conventional ventila-

tion and the cuff 10 at the different frequencies.

In the two dogs where the cuff 10 was applied at

10    5 and 11 Hz for 30 minutes while spontaneous ventilation was

occurring, in all cases $\dot{V}_{ES}$ decreased while the $PaCO_2$

changed little. The decreased $\dot{V}_{ES}$ occurred mainly as a

result of a decreased Vts while fs changed variably.

The next example was made in order to illustrate

the application of the extrathoracic high frequency compres-

sion and expansion system to improve the clearance of mucus

out of a tracheobronchial tree. It was discovered that

higher peak expiratory linear velocities occurred during

oscillation at the air-mucous interface. Furthermore, it has

20    been shown that when sputum is subjected to high frequency

oscillation in the range used herein, that is, between 3 and

17 Hz, its viscosity is reduced. This would tend to facili-

tate the removal of airway mucus, either by increased airflow

interaction or by enhancement of ciliary clearance.

Nine random-source dogs 25-35 kg. were anesthetized.

They were intubated with a shortened No. 10 endotracheal tube

and placed supine. A cuff 10 was placed around the thorax

of the dogs with the two bladders 24 and 26 positioned on

each side of the rib cage and with the caudad border of the

30    cuff at the level of the xiphisternum. The cuff was partially

inflated by a bias pressure (air flowing into the cuff at

15-20 L/min. having a variable small leak so as to not over-
compress the dog's thorax). Around this bias pressure, the
cuff pressure (Pcuff) was oscillated by the pump. The vari-
able leak was regulated so that on the withdrawal stroke of
the piston, a slightly negative cuff pressure (Pcuff)
developed. This served to partially deflate the cuff and
allow the compressed thorax to recoil back towards FRC,
thereby causing inspiratory airflow. The setup enabled
tidal volumes of 25-100 cc. at frequencies from 3-17 Hz.

10        Tracheal mucous flow was observed by direct
bronchoscopic visualization. A drop (5-10 $\mu$l) of a suspen-
sion of carbon (Animal Charcoal, Sigma) in saline was placed
on the lower tracheal mucosa just above the carina. The
leading edge of the spot was located by advancing the broncho-
scope until it just passed out of view. The position of the
bronchoscope vis-à-vis the endotracheal tube was noted and
the bronchoscope withdrawn. After a period of time, the
bronchoscope was reintroduced, the leading edge of the carbon
spot relocated, and the difference calculated. The mucous
20   clearance rate was then computed as the cephalad projection
of distance traveled (in case of spiral motion) divided by
the time elapsed. For the measurement of tracheal mucous
clearance rate during extrathoracic induced breathing, the
bronchoscope was introduced immediately before and after
rather than during the period of oscillation.

In three dogs, the variation in tracheal mucous
clearance rate (TMCR) as a function of location within the
trachea was observed. In randomized order, clearance rates
in intrathoracic trachea were compared with clearance rates
30   in extrathoracic trachea for both spontaneous breathing and
for extrathoracic induced breathing at frequencies from 3 to

- 13 -

13 Hz. No systematic intratracheal variation in clearance rate was observed in either spontaneous breathing. As a consequence, in the other dogs studied, only intrathoracic tracheal clearance was studied.

The dependence of TMCR on applied frequency was investigated in nine dogs in total. Extrathoracic induced breathing enhanced TMCR over that observed during spontaneous breathing at each frequency tested except 3 Hz. The enhancement of TMCR was sharply dependent on frequency, peaking at
10 13 Hz. The control TMCR during spontaneous breathing averaged $8.2 \pm 5.6$ (SD) mm/min; the mean rate at 13 Hz was $27.6 \pm 13.8$ mm/min, or 340% control. This difference was significant ($p < .001$).

The reproducibility of the method was examined in two ways. One dog was studied on two occasions, separated by two days. Similar baseline clearance rate and frequency dependence were observed. In a second dog, two frequency runs were performed at two different levels of anesthesia. This was accomplished by giving a bolus of pentothal followed
20 by infusion at 2 mg/kg/min during the second run instead of the usual 1 mg/kg/min. This resulted in a decrease in baseline TMCR, but no alteration in the slope of the frequency response, as shown in Figure 5.

Finally, the necessity for oscillatory airflow to occur and not just chest wall vibration in order to enhance clearance rates was investigated in three dogs by blocking the endotracheal tube during the two minutes of extrathoracic induced breathing. In each of the three experiments, no enhancement of clearance was observed with this maneuver.
30 There was, in fact, a subsequent inhibition of tracheal clearance that persisted for at least one-half hour when this

maneuver was performed.

These experiments suggest that high frequency extrathoracic induced breathing might be of great potential benefit as a mode of chest physiotherapy. This might relate to the fact that the vibration is not localized but spread over the chest walls such as to provide significant airflow. The airflow seems to be important in moving secretions. Further, the frequency range for most effective enhancement of clearances is between 11 and 15 Hz, coinciding with the natural range of cilia beat frequencies, that is, in patients where the cilia are functioning normally.

10

*Fig-1*

*Fig-1*

*Fig-2*

*Fig-3*
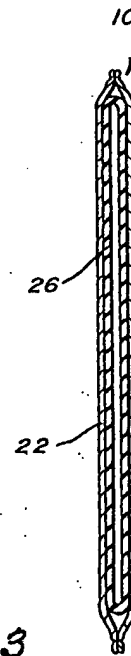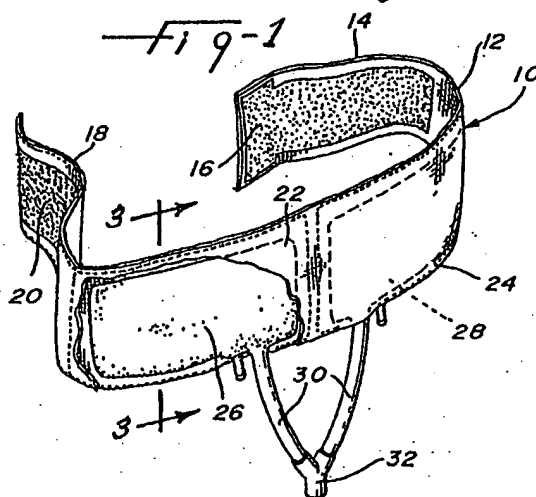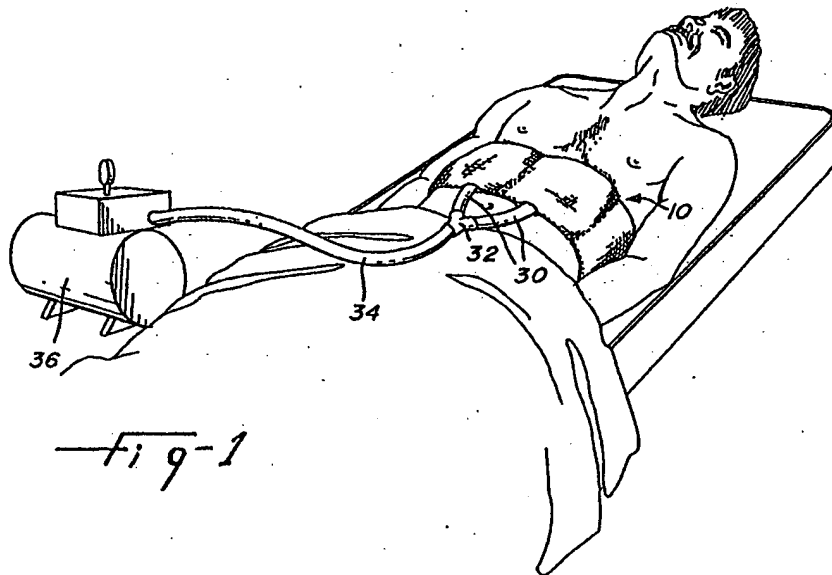
PATENT AGENTS
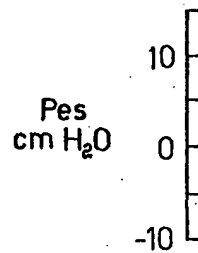
Swabey, Mitchell, Houle,
Marcoux & Sher.
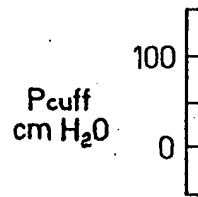
Fi g-4a



Fi g-4b
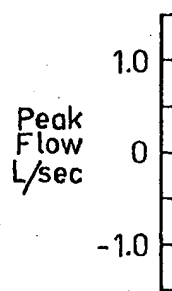


Fi g-4c
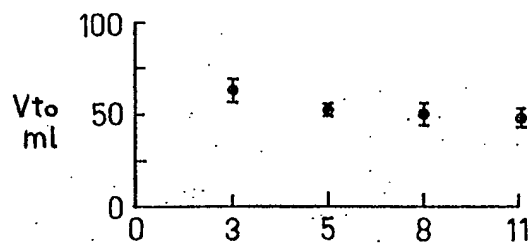


Fi g-4d

PATENT AGENTS

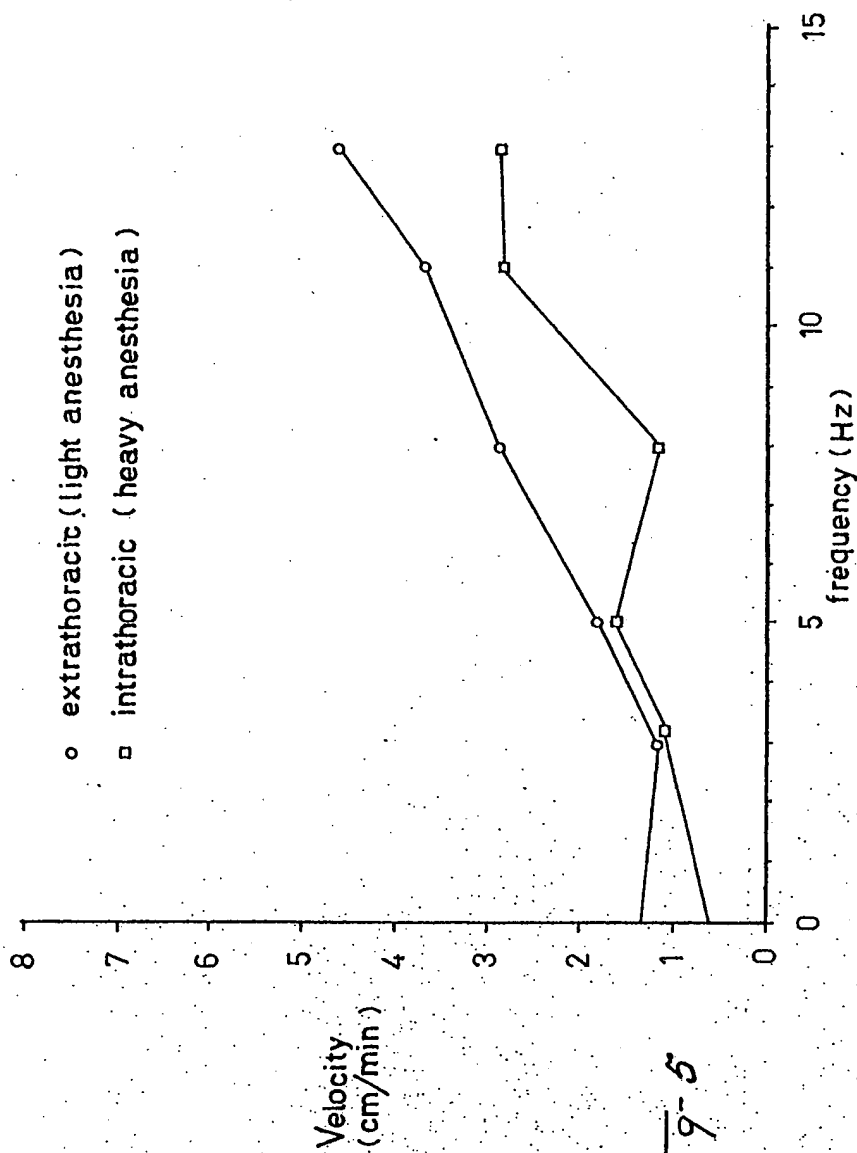Swabey, Mitchell, Houle,
Marcoux & Sher.

CARBON SPOT – DOG 2

o  extrathoracic (light anesthesia)

□  intrathoracic (heavy anesthesia)



Fig-5